Particle Film Technologies: Pest Management and Yield Enhancement Qualities in Lemons[1]

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Abstract

Surround WP and Snow were evaluated for their ability to manage citrus thrips populations in lemons on the Yuma Mesa, and their impact on lemon yield, fruit quality, and packout. Both Surround and Snow effectively controlled citrus thrips and prevented fruit scarring. Surround produced higher yields than either Snow or the commercial standard at the first harvest (#9 ring). There were no differences in yield among treatments for the second (strip) harvest, nor were their any differences in total yield. These data suggest that Surround may increase fruit earliness or sizing. There were no statistical differences among any of the treatments in fruit size frequency or quality for any of the harvests, and there was no apparent benefit from applying an additional application of Surround or Snow post thrips season solely for quality, fruit size, or yield enhancement. The activity of Surround does not appear to be adversely affected by the inclusion of the insecticides Danitol, Baythroid, Carzol, or Success, nor do these insecticides appear to be adversely affected by Surround. Foliar fertilizers did not appear to adversely affect the activity of Surround when tank mixed. However, there is some evidence that Surround may negatively affect the absorption of Fe and Mn when tank mixed with Zn, Fe, Mn lignosulfonate, but this data is not conclusive. The addition of a non-ionic surfactant appears to enhance the on-leaf distribution of Surround over light petroleum and paraffin based oils, but long term efficacy is not affected.

Introduction

Surround WP (kaolin) represents a new and unique approach to managing thrips, *Scirtothrips citri* (Moulton) in citrus. Surround is a hydrophobic mineral particle film applied in water that forms a bright white physical barrier protecting plants against certain insects and diseases. Although the leaves are covered in a white film, there is no evidence that Surround interferes with photosynthesis or stomatal conductance. Unlike conventional insecticides that control citrus thrips through rapid curative action, Surround to acts primarily as a repellent, but can cause as much as 40% direct mortality.

In addition to its action against insects, in other tree fruits, Surround has been shown to protect against sunburn, and decrease heat stress which may lead to better fruit retention, size, and yield. Previous year's data collected from citrus suggests that Surround may increase first harvest yields in citrus.

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Snow is another kaolin-based product that is similar to Surround. Snow is commonly used for citrus sunburn protection and has demonstrated activity towards citrus thrips. Currently Snow is a more cost effective alternative than Surround, but because Snow contains a greater percentage of inert materials such as silica, it is not known whether it is as effective as Surround in controlling insects, or whether it will enhance citrus yield.

In this study we compared the effects of conventional insecticides versus Surround and Snow on the development of thrips and mite populations and subsequent scarring on lemons. Additionally, we investigated the compatibility of Surround with other insecticides, foliar fertilizers, and pray adjuvants commonly used in Arizona citrus.

Materials and Methods

Large Plot Study

Fourteen-year old 'Limoneira 8A Lisbon' lemon trees grown on the Yuma Mesa were used for these studies. The test was a strip-plot design consisting of four replicates and three main plots: a commercial standard insecticide regime, Surround, and Snow. There were two sub-plots: an early-season regime where Surround and Snow were applied for citrus thrips control (as needed to maintain coverage until 85% of the fruit equaled or exceeded 1.0 inch in diameter), and a full-season regime where an additional application of Surround (kaolin) and Snow (kaolin) were applied post thrips season in attempt to enhance fruit size and retention. The early-season applications consisted of Surround at 50 lbs/ac and Snow at 80 lbs/ac applied on 5 and 17 April; and 16 May. The 16 May application included Danitol (fenpropathrin) at 21 oz/ac for control of Yuma Spider Mite, *Eotetranychus yumensis*. The commercial standard was applied as needed to maintain the thrips population at or below a 10% fruit infestation level, and as needed for spider mite control. The commercial standard consisted of Baythroid (cyfluthrin) at 6.4 oz/ac applied on 5 April, Danitol at 21 oz/ac applied on 16 May, and Success (spinosad) at 4 oz/ac applied on 24 May. The Surround and Snow treatments in the full-season treatment regimes received an additional application of 50 and 80 lbs/ac respectively, on 20 July. The commercial standard did not receive additional applications in the full-season regime sub-plots. All treatment applications included Kinetic non-ionic surfactant applied at 0.1% v/v. All treatments were applied using a PTO-driven orchard sprayer, calibrated to deliver 100 gal of spray solution per acre. The size of each sub-plot was 5 x 7 trees (0.5 ac), with trees being spaced 28 ft apart.

Pest infestation severity was estimated by sampling 50 fruit per plot for the presence or absence of immature citrus thrips and Yuma spider mites. Data are presented as a percentage of infested fruit for each pest. Fruit damage was estimated on 13 November, by visually rating the degree of scarring to the rind. Scarring was rated as 1=no scarring, 2=slight scarring partially around the stem, 3= scarring encircling the stem, 4=slight scarring on the side of the fruit and 5=major scarring on the side of the fruit. Fruit with a damage rating of 1 or 2, are not considered to be scarred enough to cause a downgrade from fancy to choice grade. Fruit with a rating of 3 are considered sufficiently scarred to be downgraded to choice grade and fruit with a rating of 4 or 5 are only considered suitable as juice grade fruit. Differences among insecticide treatments for thrips and mite infestation, and fruit damage were separated using ANOVA and an F protected LSD, $P<0.05$.

Fruit from each tree was harvested by hand using professional pickers from a local packinghouse. The experimental block was harvested two times, 1 November 2002, and 11 January 2003. For the first harvest, the pickers sized the fruit on the tree, using a #9 metal ring with a diameter of the minimum marketable size for that date, as determined by the packinghouse. All the fruit was stripped on the second. Fruit from each subplot was harvested into plastic bins, each holding 1200 lbs. of fruit. Yields for each sub-plot were estimated as whole and fractional bins of harvested fruit. Yield data, are expressed in bins of fruit per acre.

For each of the two harvests, from 15 to 45 kg of fruit was sampled from the fruit in each bin, and size (packout) data were collected from these samples. All fruits were sized using a portable optical fruit grader (Autoline, Inc., Reedley, CA). Each fruit that passed through the sorter was photographed and weighed. Weight, color, and fruit diameter data was collected for each fruit. Fruit was not physically sorted, but the data collected was stored in a computer that is an integral part of the sorter. All fruit size results are reported on a percentage basis. Differences among treatments for yield, packout, and quality were separated using ANOVA and an F protected LSD, $P<0.05$.

Small Plot Studies

These studies were conducted on eight-year-old ‘Limoneira 8A Lisbon’ lemons on *Citrus volkameriana* rootstock grown at the University of Arizona, Yuma Mesa Agricultural Center, Yuma, AZ. All trials, except the Surround – foliar fertilizer tank mix study, were randomized complete block designs with four replicates per treatment. Each plot consisted of three trees.

The Surround – foliar fertilizer study consisted of two concurrent trials; one investigating the impact of foliar fertilizers on Surround efficacy, and the other investigating the impact of Surround on foliar fertilizer leaf absorption, yield and packout quality. The trial investigating the impact of foliar fertilizers on Surround efficacy was a randomized complete block design with two trees per plot replicated four times. The trial investigating the impact of Surround on foliar fertilizers was a split-plot design with foliar fertilizers as the main effect and Surround as the sub-effect. Each plot consisted of two trees and each treatment was replicated four times.

Treatments in all the tests were applied using a piston-pump pressurized vertical boom, calibrated to deliver 100 gal/ac.

Surround – Insecticide Tank Mix Study: To determine if Surround is compatible with other foliar-applied insecticides commonly used in Arizona, Surround applied alone was compared with Surround tank mixed with insecticides for citrus thrips control. The treatments included an untreated check, Surround (kaolin) at 50 lbs/ac, Success (spinosad) at 6 oz/ac, Danitol (fenpropathrin) at 21 oz/ac, Baythroid (cyfluthrin) at 6.4 oz/ac, Dimethoate (dimethoate) at 2.0 lbs-ai/ac, Carzol (formetamate HCL) at 1.25 lbs/ac, and Surround at 50 lbs/ac tank mixed with each insecticide. However, do to an error the Surround + Dimethoate tank-mix was omitted. All treatments included the non-ionic surfactant, Kinetic, at 0.1%v/v. Treatments were applied on 18 April and 9, 16 and 24 May 2002.

Citrus thrips and Yuma spider mites populations were estimated by counting the number of fruit with at least one immature thrips or mite. Twenty-five fruit were sampled per plot. Data are presented as a percentage of infested fruit for each pest. A sample was taken 3 to 4 days after each treatment (DAT), at 7 DAT, and thereafter at weekly intervals until another application was required. Applications were triggered based on an approximate threshold of 10% infested fruit.

Prior to harvest on 18 September 2003, the fruit within each plot were visually inspected and rated for thrips and mite scarring. Scarring was rated as previous described. Differences among treatments for pest infestations and scarring were separated using ANOVA and an F protected LSD, $P<0.05$.

Surround – Foliar Fertilizer Tank Mix Study: To determine if Surround has any compatibility problem if tanked mixed with commonly used foliar fertilizers, Surround was applied alone at 50 lbs/ac, and in combination with Nutriphite at 2.0 qts/ac; Fe, Zn, Mn lignosulfonate at 2.0 qts/ac and 20-20-20 NPK at 5 lbs/ac; and Urea at 7.0 lbs/ac. Additionally, each foliar fertilizer regime was applied alone as well. An untreated check was utilized for comparison. All treatments included the non-ionic surfactant, Kinetic, at 0.1%v/v. Treatments were applied on 12 April and 7 May 2002. On 19 May, Surround alone was applied at 50 lbs/ac to all plots, except the untreated to insure protection from thrips.

Citrus thrips and Yuma spider mite populations were estimated by counting the number of fruit with at least one immature thrips or mite. Plots that received foliar fertilizer application only were not included in the thrips and mite sampling. Twenty-five fruit were sampled per plot. Data are presented as a percentage of fruit infested with immature thrips or mites. A sample was taken 3 to 4 days after each treatment, at 7 days after treatment, and thereafter at weekly intervals until another application was required. The first application was applied post petal fall before citrus thrips became numerous. Twenty-six to thirty days were allowed to elapse between the applications so that sufficient time could elapse for proper leaf collection timing for leaf nutrient analyses. The third application consisted of Surround alone at 50 lbs/ac to maintain coverage and protection from thrips until 85% of the fruit was at least 1 inch in diameter and no longer susceptible to thrips scarring. On 19 September 2002, the fruit within each plot were visually inspected and rated for thrips and mite scarring. Scarring was rated as previously described.

Leaf samples, from fully-expanded leaves of the most recent growth flush were collected before the initial application on 11 April, 29 days following the first application, and 26 days following the second application. Thirty-two leaves were sampled from each plot by removing two opposite leaves from each of eight shoots from both of the two trees in the plot . Shoots selected were about 1.5-m above the ground and were spaced evenly around the tree [2 shoots (4 leaves)selected from each quadrant of the tree]. Each sample was analyzed for N, P, K, S, Ca, Mg, Zn, Fe, Mn, and Cu by Ward Laboratories, Kearney, NE.

Fruit from each tree was harvested by hand using professional pickers from a local packinghouse. The experimental block was harvested three times, 11 October 2002, 21 November 2002, and 2 February 2003. For the first two harvests, the pickers sized the fruit on the tree, using a #9 metal ring with a diameter of the minimum marketable size for that date, as determined by the packinghouse. All the fruit was stripped on the third harvest. Fruit from each plot was harvested into plastic crates, each holding approximately 35 lbs. of fruit. Yields for each plot were estimated as whole and fractional crates of harvested fruit. Yield data, are expressed in crates of fruit per plot.

For each of the three harvests, from 15 to 45 kg of fruit was sampled from the fruit among the crates, and size (packout) data were collected from these samples. All fruits were sized using a portable optical fruit grader (Autoline, Inc., Reedley, CA). Each fruit that passed through the sorter was photographed and weighed. Weight, color, and fruit diameter data was collected for each fruit. Fruit was not physically sorted, but the data collected was stored in a computer that is an integral part of the sorter. All fruit size results are reported on a percentage basis.

Differences among treatments for pest infestations, scarring, leaf nutrients, yield, packout, and quality were separated using ANOVA and an F protected LSD, $P<0.05$.

Surround – Surfactant Study: Experience has suggested that including an adjuvant oils and spreader-stickers with Surround enhances its spray distribution. However, it is not certain which types of adjuvants perform best with Surround. In this study we evaluated a narrow range spray oil, a paraffin based spray oil, a non-ionic surfactant, and a silicone non-ionic surfactant. The treatments included an untreated check, Surround at 50 lbs/ac, and Surround at 50 lbs/ac tank mixed with NR-415 at 1 gal/ac, Agri-Dex at 0.125%v/v, Kinetic at 0.1%v/v, and Induce at 0.125%v/v. Treatments were applied on 17 May 2002.

Citrus thrips populations were estimated by counting the number of fruit with at least one immature thrips. Twenty-five fruit were sampled per plot. Data are presented as a percentage of fruit infested with immature thrips. Samples were taken 6, 12, and 20 days after treatment. Differences among treatments for thrips infestation were separated using ANOVA and an F protected LSD, $P<0.05$.

In addition to the field study, 60 new fully expanded citrus leaves were collected from the field and brought into the laboratory. Ten leaves were treated with each: Surround at 50 lbs/100 gal, and Surround at 50 lbs/100 gal tank mixed with NR-415 at 1 gal/100 gal, Agri-Dex at 0.125%v/v, Kinetic at 0.1%v/v, and Induce at 0.125%v/v. The treatments were applied with a hand pumped spray bottle. The leaves were allowed to dry for 1 hour, and then they were visually accessed for the coverage of the Surround.

Results and Discussion

Large Plot Study

Citrus thrips were fairly low among all plots in this study throughout the season. Based on an action threshold of 10% infested fruit, the thrips populations reached damaging levels in mid-April and then not again until late-May (Figure 1). Following the first application on 5 April the citrus thrips population declined rapidly. Generally, Surround and Snow are thought to act primarily as repellents, and are not known for causing a rapid reduction in the thrips population. However cage studies have demonstrated that Surround and Snow can result in 40% direct mortality of citrus thrips. Surround and Snow were applied three times to insure coverage of new citrus growth and the citrus thrips population in these treatment regimes remained low (<2% infestation) throughout the remainder of the thrips susceptibility period (Figure 1). There were no significant in the thrips populations between Surround and Snow. In the standard treatment regime, Baythroid was used for the initial application, and reduce the thrips population to 3.75% at 6 days after treatment and did not statistically differ from the Surround and Snow treatments.

The population in the standard regime continued to decline to 1.25% on 19 April. Although the thrips population was extremely low in the standard regime on 19 April, it was statistically higher than in the particle film treatments (Figure 1). By 14 May the thrips populations in the standard regime were beginning to increase, reaching 7% infestation and was significantly greater than the Surround and Snow, which had 1.25 and 1.5% infestations respectively.

By 14 May, Yuma spider mites were beginning to buildup throughout the test with populations on 14 May ranging from 0.5 to 1.1 mites per fruit (Figure 2). There were no significant differences among the treatments. On 16 May, Danitol was applied to the standard regime for mite and thrips control, and was included with the Surround and Snow treatments for mite control. Yuma spider mite populations were effectively controlled in all plots (Figure 2). However, Danitol was not effective in reducing the thrips population in the commercial standard regime where the population increased to 11% infestation, which was significantly greater than Surround and Snow which had 0.0 and 1.75% infested fruit respectively (Figure 1). The reason Danitol failed to control the citrus thrips is not certain, but insecticide resistance is suspected. Resistance of citrus thrips to Danitol has been reported as early as 1993. The standard regime was treated again on 24 May with Success which effectively reduced the thrips population to 0.0% infestation, similar to Snow and Surround. Citrus thrips populations remained low until the end of the susceptibility period on 15 June (Figure 1).

Based on visual inspections and ratings, there were no significant differences among the treatments in thrips or mite scarring (Figure 3). The amount of fancy grade fruit based solely on thrips and mite scarring, was >90% in all treatments.

We could not detect any statistical benefit in yield from applying an additional application of Surround or Snow in July in addition to applications applied for citrus thrips control (Figure 4). However, plots treated with Surround for thrips management produced a significantly higher yield at first harvest than those treated with either Snow or the Standard regime. The Surround plots yielded 12.9 plastic bins per acre relative to 10.44 and 10.59 bins per acre in the Snow and Standard treatments respectively (Figure 4). There were no significant differences among treatments in yield at the second harvest or in total yield (Figure 4). The benefit in early yield increase with Surround when applied for thrips control is also evident when looking at percentage yield at first harvest (Figure 5). Surround yielded 46.8% of its yield at first harvest relative to 41.3 and 39% for Snow and the Standard regimes respectively (Figure 5).

Based on the packout of the first harvest, there were no significant differences among treatments in the percentages of fruit sizes harvested or quality, nor was there any benefit from an additional application of particle films in July over only applications timed for thrips management (Figures 6 & 7). Similar results were observed at second harvest, but the quality of fruit was better at first harvest than at second harvest (Figures 8 & 9). Since the first harvest was picked using #9 rings, the data for fruit size is biased towards uniform sizes. Because the Surround plots yielded more at first harvest than the other treatments (Figure 4), this suggests that the fruit in the Surround plots sized faster than in the other treatments. We have observed this trend for the past three years. Harvesting more fruit early has important economic implications since lemon prices are traditionally higher during the period when the first harvest occurs, and the fruit at first harvest is traditionally higher is quality as well. The fact that Surround increased yields during the first harvest over Snow and the standard regime suggests that Surround may increase earliness to some extent through reduction of leaf temperature without negatively impacting stomatal conductance and photosynthesis. Because of the higher proportion of inert substances in Snow over Surround suggests that Snow may have a slight negative impact on stomatal conductance and/or photosynthesis.

Small Plot Studies

Surround – Insecticide Tank Mix Study: When tank mixed with Danitol, Baythroid or Carzol, Surround did not adversely affect those insecticides ability to control citrus thrips relative to when they were used alone (Tables 1 & 3). When Surround was mixed with Success, the tank mix had more infested fruit than Success alone, but only on one sample date, 28 May (Table 1). The fact that this effect was not observed following the first three applications suggests that it may be an aberration in the data rather than an indication of incompatibility.

Several insecticides benefited from the inclusion of Surround (Tables 1 & 3). Danitol + Surround exhibited fewer thrips infested fruit than Danitol alone on 2, 20, 23, 28, and 31 May, and on 7 June. Overall, Danitol alone was not an effective treatment, except the first week following the first application. Following the first two applications Baythroid + Surround did not differ from Baythroid alone (Table 1). However, at seven days after application 3, and 4, 7, and 13 days after application 4, Baythroid + Surround contained significantly fewer thrips infested fruit than Baythroid alone. Other studies have supported the finding that Baythroid is not a highly effective citrus thrips treatment late in the season. At no point did trees treated with Danitol, Baythroid, Dimethoate, Carzol, or Success alone, or in combination with Surround, contain significantly fewer thrips than Surround alone (Tables 1 & 3).

Yuma spider mites were common in this trial reaching fairly high numbers, particularly early in the season (Table 2). On 25 April, 15 and 28 May, all of the treatments contained fewer mites than the untreated although Danitol is considered to be the only product evaluated with good miticidal properties, and in general Danitol appeared to be the best product evaluated (Tables 2 & 3).

Scarring throughout this trial was higher than normally expected, probably due to high thrips populations encountered at petal-fall, prior to initiation of the study (Figure 10). However, the amount of fruit scarred to the point of being classified as juice quality was still low. All of the treatments produced higher quality fruit than the untreated. Success, Surround + Success and Surround + Baythroid produced higher quality fruit than Danitol alone. We could not detect any significant differences among any of the remaining treatments.

Surround – Foliar Fertilizer Tank Mix Study: The inclusion of foliar fertilizers with Surround did not appear to interfere with the ability of Surround to control citrus thrips (Tables 4 & 6). However on 3 May, Surround + Nutriphite did have significantly more thrips infested fruit than Surround alone; but this finding was not a trend and may have been an aberration in the data. Surround did appear to have some activity on Yuma spider mite, but this activity was not high enough to justify its use as a miticide (Tables 5 & 6). Similar to thrips, the foliar fertilizer did not appear to affect Surrounds impact on mites (Tables 5 & 6). Treatments of Surround alone or with the foliar fertilizers did not differ in the percentage of fancy grade fruit produced based on thrips or mite scarring (Figure 12). All the treatments produced higher quality fruit than the untreated.

We did not detect any differences in yields at any of the harvests dates, for total yield, or for the packout fruit sizes among any of the treatments (Figures 13, 14, 15 and 16). Similar to the visual quality ratings for thrips scarring, all of the treatments produced higher quality fruit than the untreated at first harvest (Figure 17). However, we could not detect and differences in packout quality among treatments at second harvest (Figure 18), and at third harvest, there appeared to be more choice fruit in the untreated than in the Surround, Surround + Nutriphite, or Surround + Fe, Zn, Mn lignosulfonate + NPK plots (Figure 19). These differences at third harvest, although statistically significant, are probably not commercially significant.

We did not detect any significant effects or interactions from Surround and foliar fertilizers on N, P, K, S, Ca, or Mg content in leaves following either application (Tables 7 & 8). However, since the trees utilized in this study were fertilized with N and P regularly during irrigation, the potential effects from Surround on N and P containing foliar fertilizer may have been masked.

We did detect significant foliar fertilizer effects for Zn following both applications (6 May, $P = 0.045$; 2 June, $P = .0008$) (Table 9), and for Fe and Mn following the second application (Fe, $P = 0.005$; Mn, $P = 0.02$) (Figures 19 & 20). Thus it appears that Fe, Zn, Mn lignosulfonate + 20-20-20 NPK fertilizer treatment was able to increase Zn content in the leaves regardless of Surround. Additionally, for Fe and Mn following the second application, we detected significant effects from Surround (Fe, $P = 0.044$; Mn 0.0051) and an interaction between the fertilizers and Surround (Fe, $P = 0.008$; Mn, $P = 0.018$) (Figures 19 & 20). Contrary to what we observed for Zn, these data suggest that Surround may have interfered with Fe and Mn absorption in the Fe, Zn, Mn lignosulfonate + 20-20-20 NPK fertilizer treatment (Figure 19). However, a similar response was noted for Fe content from the Nutriphite treatment, and to a lesser extent, urea; and for Mn for the urea treatment and to a lesser extent Nutriphite. Neither Nutriphite nor urea supply Fe or Mn; thus these findings are suspect. We also detected effects from Surround on Cu content in leaves following the second application, $P = 0.04$ (Table 10). The reason plots treated with Surround would contain more Cu than the untreated is not certain. Perhaps the Surround causes the tree to conserve Cu, a significant portion of Surround's inert content is Cu, or it is an aberration in the data.

Surround – Surfactant Study: Based on visual observations of lemon leaves treated in the laboratory with Surround at 50 lbs/ac with and without various surfactants, the surfactant choice does appear to influence leaf spray coverage (Table 11). Neither the NR-415 (light petroleum oil) nor the Agri-Dex (paraffin based petroleum oil) appeared to enhance Surround distribution over Surround alone. Both non-ionic surfactants (Kinetic and Induce) appeared to improve Surround distribution over the leaf (Table 11).

In the field at six days after treatment, all of the treatments except Surround mixed with NR-415 oil had a significantly lower thrips infestation that the untreated (Figure 21). However, by day 12 and 20, all of the treatments with Surround were similar in thrips infestation and all were lower than the untreated. Although on-leaf spray distribution is enhanced with non-ionic surfactants, it does not appear to be critical for adequate control of citrus thrips. The reason Surround + NR-415 did not perform well at six days after treatment is not certain. If it were solely due to on leaf distribution similar results would be expected for Surround alone and Surround + Agri-Dex.

Table 1. Effect of insecticide alone or mixed with Surround on citrus thrips infestation on lemon fruit, Yuma Mesa 2002.

		Mean percentage of fruit infested with immature citrus thrips										
Treatment	Rate	Apr 22 4 DAT 1	Apr 25 7 DAT 1	May 2 14 DAT 1	May 7 19 DAT 1	May 13 4 DAT 2	May 15 6 DAT 2	May 20 4 DAT 3	May 23 7 DAT 3	May 28 4 DAT 4	May 31 7 DAT 4	June 7 13 DAT 4
Untreated		8.00a	35.00a	32.00a	52.00a	32.00a	29.00a	35.00a	30.00a	30.00a	29.00b	29.00a
Danitol	21 oz/ac	1.00a	3.00b	31.00a	22.00bc	12.00bcd	27.00ab	36.00a	28.00a	25.00a	43.00a	30.00a
Baythroid	6.4 oz/as	4.00a	2.00b	9.00b	13.00cd	10.00bcd	15.00cde	14.00bc	24.00abc	18.00ab	20.00bc	15.00b
Dimethoate	2.0 lbs-ai/ac	5.00a	4.00b	9.00b	19.00bcd	14.00bc	30.00a	14.00bc	26.00ab	11.00cde	26.00b	26.00a
Carzol	1.25 lbs/ac	1.00a	3.00b	4.00b	25.00b	11.00bcd	16.00cde	3.00bc	3.00d	0.00f	1.00d	1.00d
Success	6 oz/ac	0.00a	11.00b	6.00b	11.00cd	6.00bcd	8.00de	1.00c	7.00d	1.00ef	5.00d	7.00bcd
Surround	50 lbs/ac	5.00a	4.00b	12.00b	17.00bcd	13.00b	6.00e	7.00bc	13.00bcd	6.00def	8.00cd	0.00d
Sur+Dan	50 lbs+21 oz/ac	0.00a	4.00b	8.00b	17.00bcd	8.00bcd	17.00bcd	8.00bc	9.00d	6.00def	5.00d	3.00d
Sur+Bay	50 lbs+6.4 oz/ac	4.00a	2.00b	4.00b	10.00d	5.00b	9.00de	8.00bc	7.00d	3.00def	4.00d	5.00cd
Sur+Car	50 lbs+1.25 lbs/A	1.00a	5.00b	7.00b	12.00cd	3.00cd	7.00de	4.00bc	7.00d	4.00def	3.00d	7.00bcd
Sur+Suc	50 lbs+6 oz/ac	3.00a	2.00b	13.00b	10.00d	4.00cd	8.00de	2.00c	10.00cd	12.00cd	4.00d	2.00d

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD.

Table 2. Effect of insecticide alone or mixed with Surround on Yuma spider mites on lemon leaves, Yuma Mesa 2002.

		Mean percentage of fruit infested with mites										
Treatment	Rate	Apr 22 4 DAT 1	Apr 25 7 DAT 1	May 2 14 DAT 1	May 7 19 DAT 1	May 13 4 DAT 2	May 15 6 DAT 2	May 20 4 DAT 3	May 23 7 DAT 3	May 28 4 DAT 4	May 31 7 DAT 4	June 7 13 DAT 4
Untreated		0.00a	2.31a	4.09a	4.38a	1.34a	2.48a	0.78a	0.58a	1.00a	0.40a	0.12a
Danitol	21 oz/ac	0.00a	0.09c	0.72a	0.88a	0.36a	0.18de	0.12a	0.44a	0.20b	0.12a	0.16a
Baythroid	6.4 oz/ac	0.00a	0.13c	2.94a	1.68a	1.06a	0.14de	0.10a	0.20a	0.28b	0.40a	0.10a
Dimethoate	2.0 lbs-ai/ac	0.00a	0.22bc	0.92a	1.78a	0.62a	0.68bcde	0.26a	0.22a	0.22b	0.20a	0.18a
Carzol	1.25 lbs/ac	0.00a	0.30bc	1.00a	2.98a	0.82a	0.36cde	0.16a	0.44a	0.46b	0.46a	0.26a
Success	6 oz/ac	0.00a	0.64bc	1.38a	2.44a	0.74a	1.38b	0.48a	0.22a	0.10b	0.14a	0.20a
Surround	50 lbs/ac	0.00a	1.04b	2.04a	2.34a	1.22a	1.02bc	0.24a	0.12a	0.14b	0.06a	0.04a
Sur+Dan	50 lbs+21 oz/ac	0.00a	0.03c	0.50a	2.04a	0.28a	0.36cde	0.16a	0.10a	0.04b	0.16a	0.02a
Sur+Bay	50 lbs+6.4 oz/ac	0.00a	0.30bc	1.82a	0.88a	0.46a	0.28cde	1.18a	0.18a	0.28b	0.24a	0.10a
Sur+Car	50 lbs+1.25 lbs/ac	0.00a	0.28bc	2.14a	3.66a	0.98a	1.32b	0.44a	0.20a	0.12b	0.16a	0.18a
Sur+Suc	50 lbs+6 oz/ac	0.00a	0.38bc	1.72a	1.74a	0.36a	0.60bcde	0.08a	0.28a	0.12b	0.04a	0.14a

Means in a column followed by the same letter are not significantly different based on an F protected ($P<0.05$) LSD.

Table 3. Pooled data by days after treatment (DAT) for citrus thrips and Yuma spider mites on lemons when Surround is tank-mixed with insecticides, Yuma Mesa 2002.

Treatment	Rate	3-4 DAT, n=4		6-7 DAT, n=4		13-14 DAT, n=2		19 DAT, n=1	
		Thrips	Mites	Thrips	Mites	Thrips	Mites	Thrips	Mites
Untreated		26.25a	0.78a	30.75a	1.44a	30.50a	2.11a	52.00a	4.38a
Danitol	21 oz/ac	18.50b	0.17bcd	25.25ab	1.80cd	30.50a	0.44a	22.00bc	0.88a
Baythroid	6.4 oz/ac	11.50c	0.36bcd	15.25c	0.22bcd	12.00bc	1.52a	13.00cd	1.68a
Dimethoate	2.0 lbs-ai/ac	11.00c	0.28bcd	21.50b	0.33bcd	17.50b	0.55a	19.00bcd	1.78a
Carzol	1.25 lbs/ac	3.75ef	0.36bcd	5.75e	0.39bcd	2.50d	0.63a	25.00b	2.98a
Success	6 oz/ac	2.00f	0.33bcd	7.75de	0.60b	6.50cd	0.79a	11.00cd	2.44a
Surround	50 lbs/ac	7.75cde	0.40b	7.75de	0.56bc	6.00cd	1.04a	17.00bcd	2.34a
Sur+Dan	50 lbs+21 oz/ac	5.50def	0.12d	8.75de	0.16d	5.50cd	0.26a	17.00bcd	2.04a
Sur+Bay	50 lbs+6.4 oz/ac	5.00def	0.23bcd	5.50e	0.25bcd	4.50cd	0.96a	10.00d	0.88a
Sur+Car	50 lbs+1.25 lbs/ac	3.00ef	0.39bc	5.50e	0.49bcd	7.00cd	1.16a	12.00cd	3.66a
Sur+Suc	50 lbs+6 oz/ac	5.25def	0.14bcd	6.00e	0.33bcd	7.50cd	0.93a	10.00d	1.74a

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD.

Table 4. Effect of Surround / fertilizer tank mixes on citrus thrips infestation on lemon fruit, Yuma Mesa 2002.

		Mean percentage of fruit infested with immature citrus thrips							
Treatment	Rate	Apr 15 3 DAT 1	Apr 19 7 DAT 1	Apr 26 14 DAT 1	May 3 21 DAT 1	May 14 7 DAT 2	May 24 7 DAT 3	May 31 14 DAT 3	June 6 20 DAT 3
Untreated		12.00a	15.00a	30.00a	29.00a	49.00a	49.00a	35.00a	11.00a
Surround	50lbs/ac	0.00b	1.00b	10.00b	7.00c	19.00b	19.00b	4.00b	1.00b
Sur+Nutri	50lbs+2qts/ac	0.00b	5.00b	7.00b	16.00b	15.00b	15.00b	11.00b	2.00b
Sur+Micro+NPK	50lbs+2qts+2lbs/ac	3.00b	5.00b	4.00b	13.00bc	14.00b	14.00b	6.00b	4.00b
Sur+Urea	50lbs+7lbs/ac	3.00b	7.00b	15.00ab	8.00bc	16.00b	16.00b	9.00b	4.00b

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Sur = Surround; Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

Table 5. Effect of Surround / fertilizer tank mixes on Yuma spider mites on lemon leaves, Yuma Mesa 2002.

		Mean percentage of fruit infested with mites							
Treatment	Rate	Apr 15 3 DAT 1	Apr 19 7 DAT 1	Apr 26 14 DAT 1	May 3 21 DAT 1	May 14 7 DAT 2	May 24 7 DAT 3	May 31 14 DAT 3	June 6 20 DAT 3
Untreated		0.00a	0.00a	4.70a	3.98a	3.14a	1.36a	0.70a	0.36a
Surround	50lbs/ac	0.00a	0.00a	1.10b	4.34a	1.26a	0.40a	0.14b	0.10b
Sur+Nutri	50lbs+2qts/ac	0.00a	0.00a	1.36b	1.20a	1.06a	0.34a	0.14b	0.10b
Sur+Micro+NPK	50lbs+2qts+2lbs/ac	0.00a	0.00a	2.11b	1.20a	0.82a	0.18a	0.18b	0.10b
Sur+Urea	50lbs+7lbs/ac	0.00a	0.00a	0.86b	1.54a	1.76a	0.62a	0.44ab	0.34a

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Sur = Surround; Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

Table 6. Pooled data by days after treatment (DAT) for citrus thrips and Yuma spider mites on lemons when Surround is tank-mixed with foliar fertilizers, Yuma Mesa 2002.

Treatment	Rate	3 DAT, n=1		7 DAT, n=3		14 DAT, n=2		20-21 DAT, n=2	
		Thrips	Mites	Thrips	Mites	Thrips	Mites	Thrips	Mites
Untreated		12.00a	0.00a	33.33a	1.50a	32.50a	2.70a	20.00a	2.21a
Surround	50lbs/A	0.00b	0.00a	9.33b	0.55a	7.00b	0.62b	4.00b	2.22a
Sur+Nutri	50lbs/A+2qts/A	0.00b	0.00a	11.33b	0.47a	9.00b	0.75b	9.00b	0.65a
Sur+Micro+NPK	50lbs+2qts/A+2lbs/A	3.00b	0.00a	9.67b	0.33a	5.00b	1.15b	8.50b	2.04a
Sur+Urea	50lbs+7lbs/A	3.00b	0.00a	11.67b	0.79a	12.00b	0.65b	6.00b	0.94a

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Sur = Surround; Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

Table 7. Effect of Surround / fertilizer tank mixes on the uptake of nutrients from foliar fertilizers by lemon leaves 24 days after a single application, Yuma Mesa, 6 May 2002.

Treatment	Rate	%N	%P	%K	%S	%Ca	%Mg	Fe (ppm)	Mn (ppm)	Cu (ppm)
Untreated		1.94a	0.10a	1.47a	0.22a	3.69a	0.28a	64.75a	17.00a	5.43a
Surround	50lbs/A	1.77a	0.09a	1.31a	0.22a	4.41a	0.31a	51.00a	10.50a	6.00a
Sur+Nutri	50lbs/A+2qts/A	1.73a	0.09a	1.27a	0.23a	4.10a	0.29a	79.00a	14.25a	4.95a
Sur+Micro+NPK	50lbs+2qts/A+2lbs/A	1.69a	0.08a	1.18a	0.25a	4.64a	0.30a	66.50a	20.25a	5.58a
Sur+Urea	50lbs+7lbs/A	1.71a	0.08a	1.21a	0.23a	4.39a	0.30a	72.00a	15.25a	5.80a
Nutri	2qts/A	1.80a	0.08a	1.28a	0.21a	4.27a	0.31a	74.50a	18.50a	4.43a
Micro+NPK	2qts/A+2lbs/A	1.57a	0.09a	1.30a	0.26a	4.05a	0.28a	75.25a	21.25a	5.35a
Urea	7lbs/A	1.69a	0.08a	1.37a	0.20a	3.87a	0.27a	62.00a	21.00a	5.35a

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Sur = Surround; Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

Table 8. Effect of Surround / fertilizer tank mixes on the uptake of nutrients from foliar fertilizers by lemon leaves 26 days after a second application and 50 days after the first application, Yuma Mesa, 2 June 2002.

Treatment	Rate	%N	%P	%K	%S	%Ca	%Mg
Untreated		2.25a	0.12a	1.59a	0.24a	4.06a	0.34a
Surround	50lbs/A	2.00a	0.10a	1.45a	0.24a	4.82a	0.33a
Sur+Nutri	50lbs/A+2qts/A	2.16a	0.12a	1.58a	0.25a	4.10a	0.32a
Sur+Micro+NPK	50lbs+2qts/A+2lbs/A	2.10a	0.11a	1.45a	0.23a	4.52a	0.34a
Sur+Urea	50lbs+7lbs/A	2.12a	0.11a	1.46a	0.24a	4.11a	0.33a
Nutri	2qts/A	2.03a	0.10a	1.33a	0.23a	4.95a	0.35a
Micro+NPK	2qts/A+2lbs/A	2.00a	0.11a	1.45a	0.27a	5.04a	0.34a
Urea	7lbs/A	1.98a	0.10a	1.27a	0.25a	5.16a	0.34a

Means in a column followed by the same letter are not significantly different based on an F protected ($P<0.05$) LSD.
Sur = Surround; Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

Table 9. Effect of foliar fertilizers on Zn (ppm) in lemon leaves, Yuma Mesa Agricultural Center, Yuma, AZ[1].

Treatment	Rate	May 6	June 2
Untreated		7.63b	8.38b
Nutriphite	2qts/ac	6.62b	8.88b
Fe, Zn, Mn lignosulfonate + 20-20-20 NPK	2qts/ac + 2lbs/ac	9.75a	14.88a
Urea	7lbs/ac	6.25b	10.13b

Means in a column followed by the same letter are not significantly different based on an F protected ($P<0.05$) LSD.
[1]Foliar fertilizer means pooled across Surround effects since no Surround effects or interactions were detected. Treatments applied 12 April and 19 May, 2002. Zn content on 11 April before applications = 10.58 ppm across treatments.

Table 10. Effect of Surround on Cu (ppm) in lemon leaves, Yuma Mesa Agricultural Center, Yuma, AZ, 2 June 2002[1].

Treatment	Rate	Cu (ppm)
Untreated		3.91a
Surround	50 lbs/ac	4.44b

Means in a column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD.
[1]Data for Surround and the untreated were pooled across foliar fertilizers since no significant fertilizer effects or interactions were detected. Treatments applied 12 April and 19 May, 2002. Cu content on 11 April before applications = 3.55 ppm across treatments.

Table 11. Visual observations of the distribution of Surround alone or with various adjuvants sprayed on fully expanded lemon leaves.

Surfactant	Type	Visual Observation
NR-415	Light petroleum oil commonly used in desert citrus	The Surround tended to be segregated into “specks” and didn’t spread the product more than using Surround alone.
Agri-Dex	Paraffin based Petroleum oil adjuvant	The Surround tended to be segregated into “specks” and didn’t spread the product more than using Surround alone.
Kinetic	Non-ionic silicone spreader	The surfactant appeared to improve coverage, spreading the Surround fairly evenly than Surround alone.
Induce	Non-ionic non-silicone spreader	The surfactant appeared to improve coverage, spreading the Surround fairly evenly than Surround alone.
Surround	Product with nothing added	Surround alone tended to be segregated into “specks” and didn’t spread very evenly.

Surround was applied at 50 lbs/A, NR-415 at 1 gal/A, Agri-Dex at 0.125% v/v, Kinetic at 0.1% v/v, and Induce at 0.125% v/v. The spray volume was 100 gal/A.

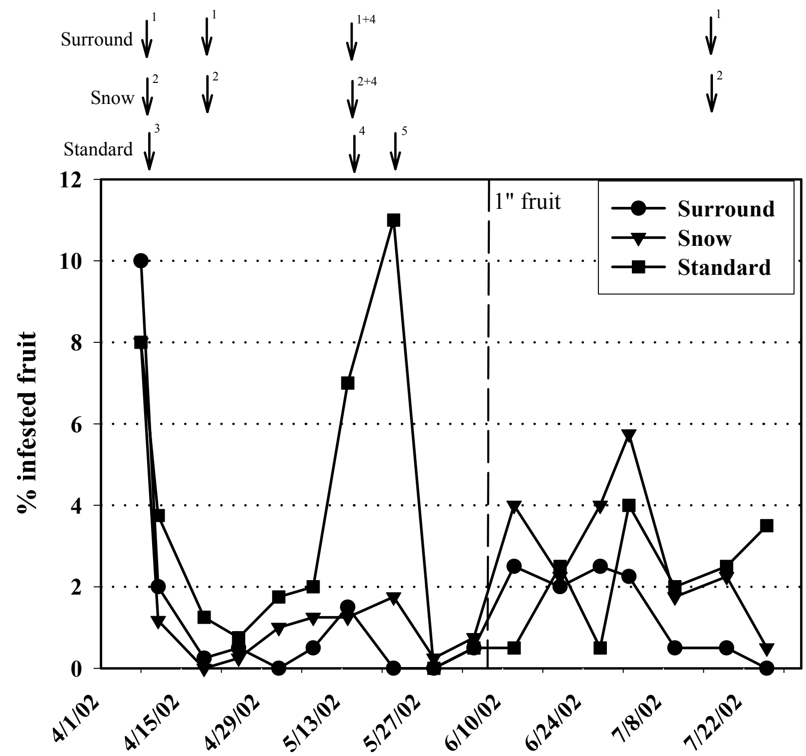

Figure 1. Percentages of lemon fruit infested with at least one immature citrus thrips. [1]Surround 50lbs/ac, [2]Snow 80 lbs/ac, [3]Baythroid 6.4 oz/ac, [4]Danitol 21oz/ac, [5]Success 8 oz/ac.

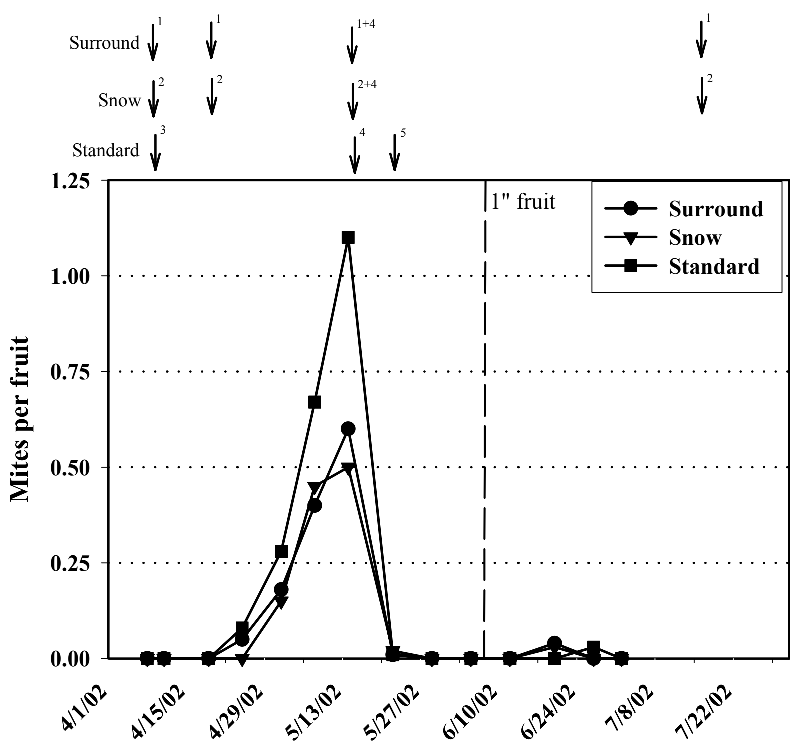

Figure 2. Number of Yuma spider mites per lemon fruit. [1]Surround 50lbs/ac, [2]Snow 80 lbs/ac, [3]Baythroid 6.4 oz/ac, [4]Danitol 21oz/ac, [5]Success 8 oz/ac.

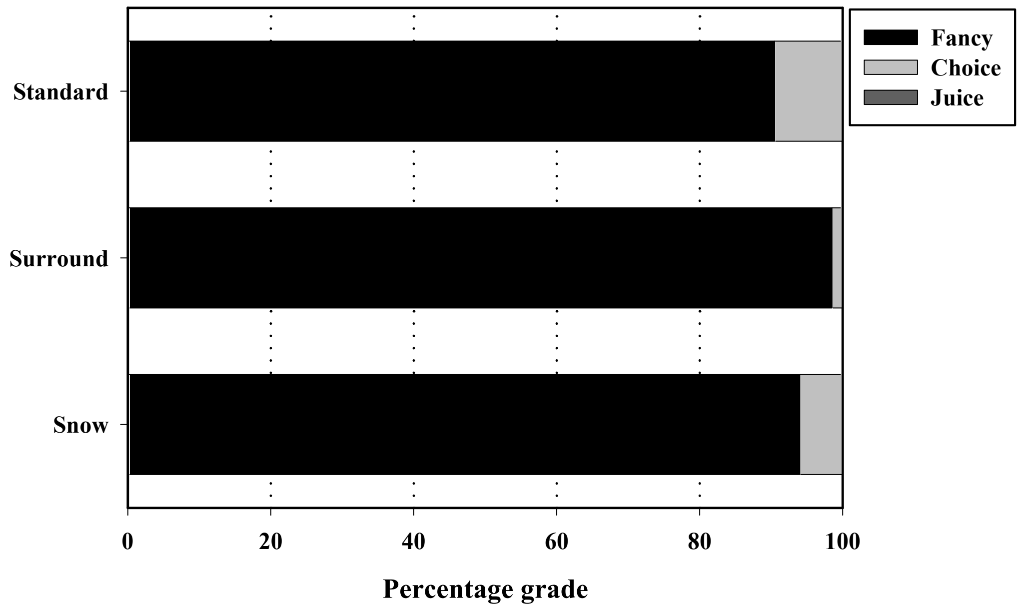

Figure 3. Percentage of fancy, choice and juice grade lemons due to thrips scarring at first harvest, 13 November 2002.

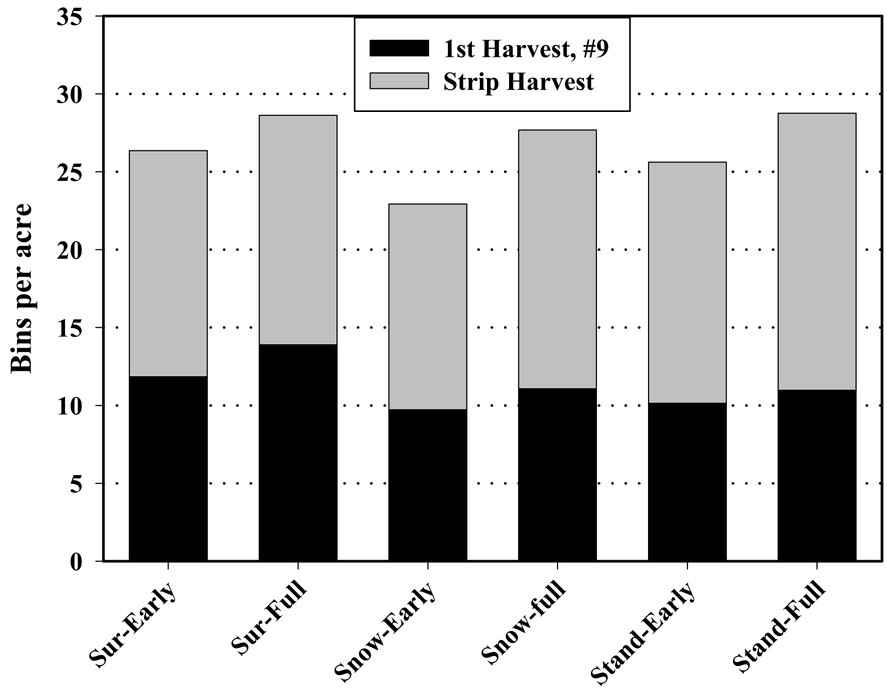

Figure 4. Yield of lemons from plots treated with Surround or Snow particle films, or with commercial standard insecticides (first harvest on 1 November 2002, strip harvest on 11 January 2003).

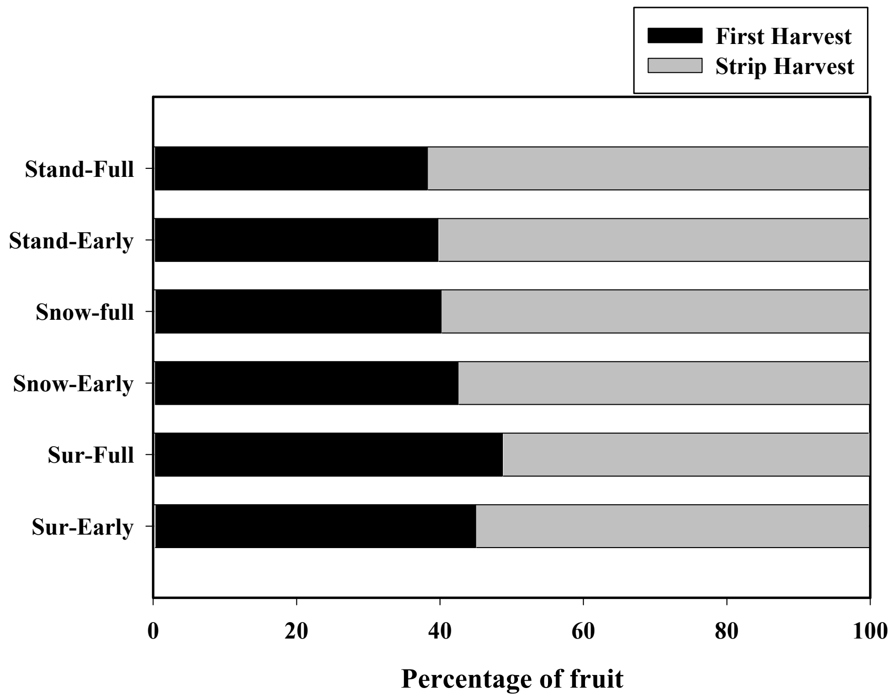

Figure 5. Percentage of lemon fruit picked during first or stripped harvest relative to total yield from plots treated with Surround or Snow particle films, or with commercial standard insecticides (first harvest on 1 November 2002, strip harvest on 11 January 2003).

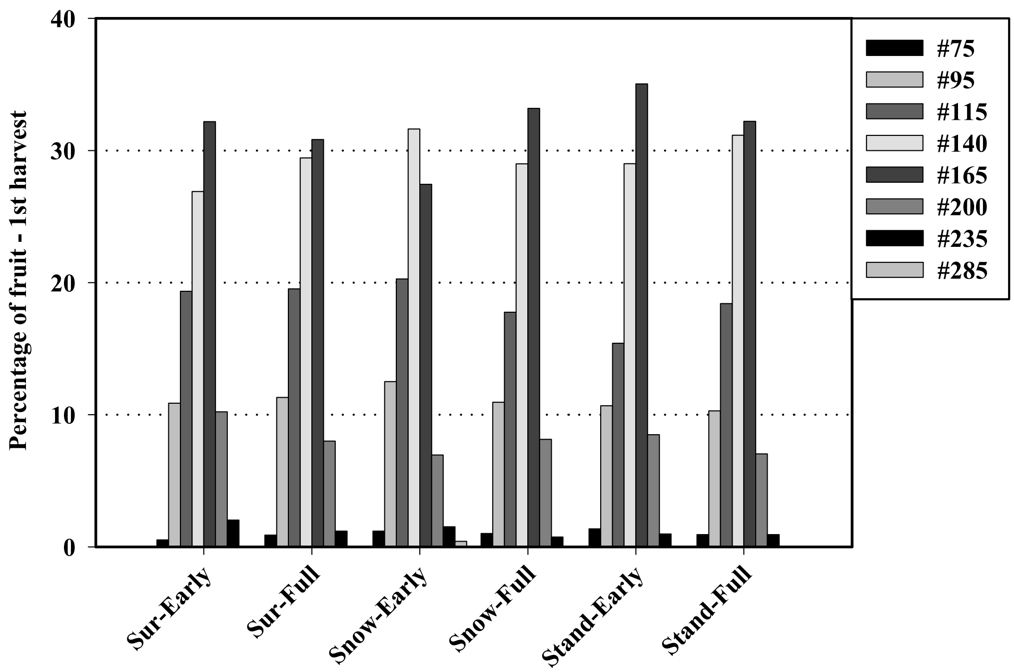

Figure 6. Effects of Surround and Snow particle films on fruit size at first harvest (#9 ring), on 1 November 2002.

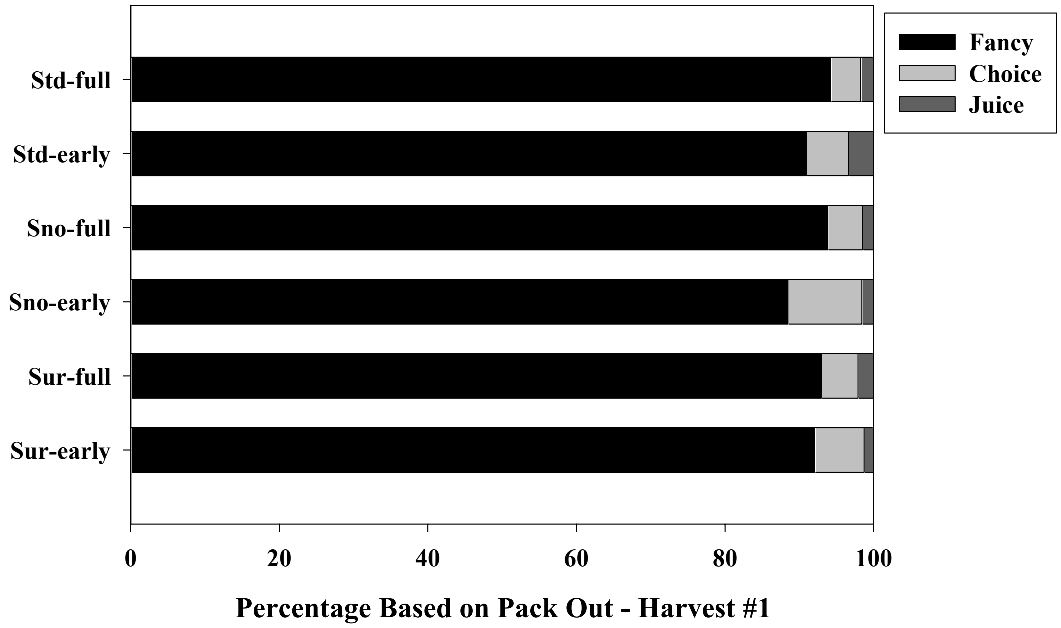

Figure 7. Effects of Surround and Snow particle films on fruit quality at first harvest (#9 ring), on 1 November 2002.

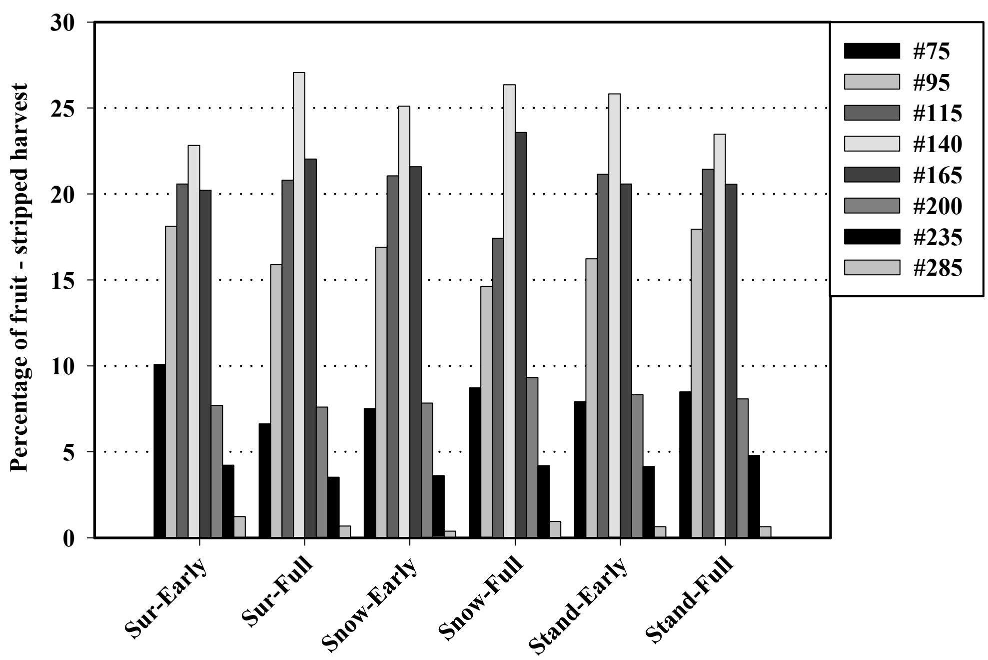

Figure 8. Effects of Surround and Snow particle films on fruit size at second harvest (stripped), on 11 January 2003.

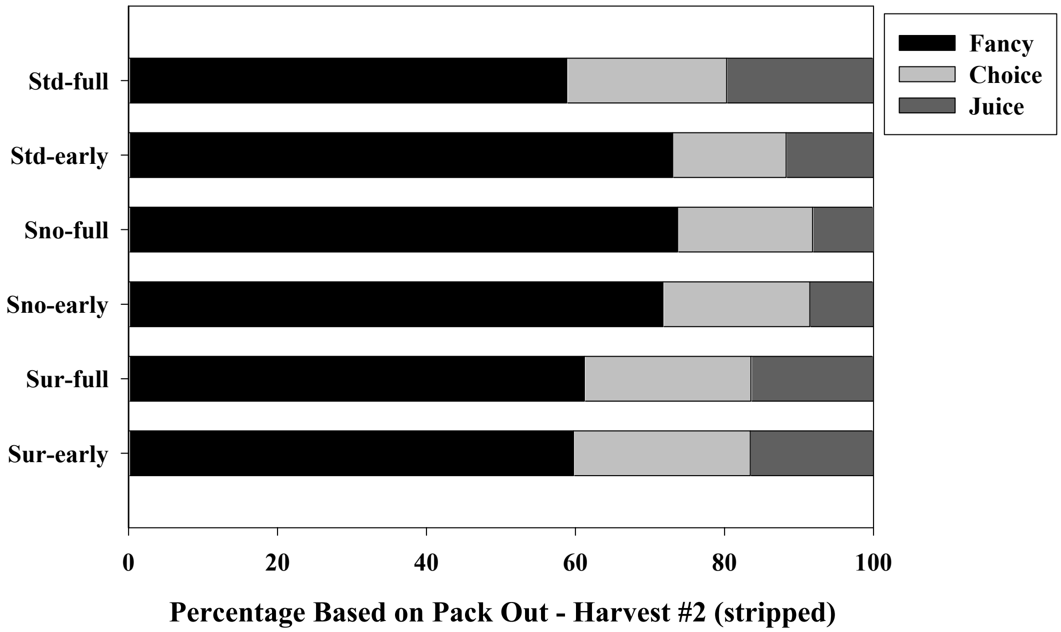

Figure 9. Effects of Surround and Snow particle films on fruit quality at the second harvest (stripped), on 11 January 2003.

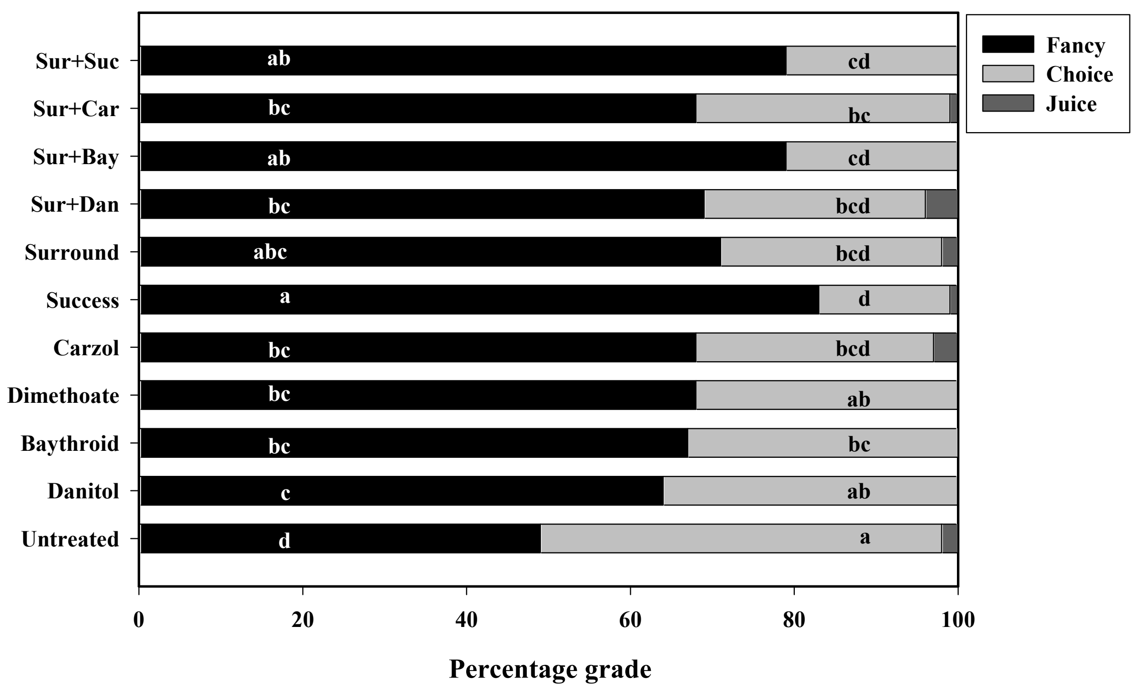

Figure 10. Percentage of fruit graded as fancy, choice, or juice quality based on thrips and mite scarring. Bars in column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD.

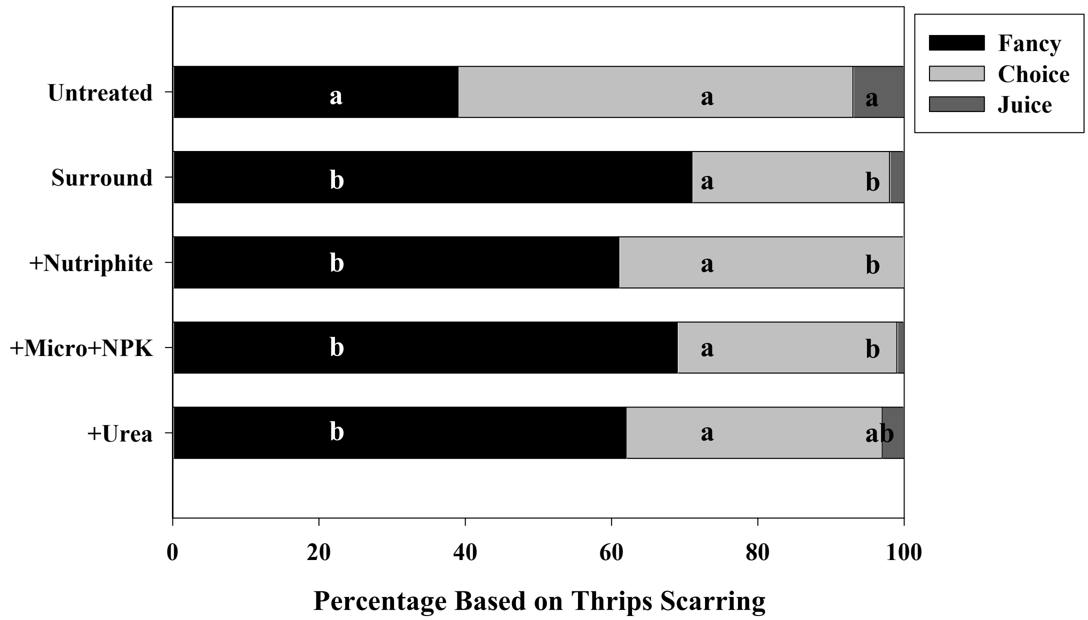

Figure 11. Percentage of fruit graded as fancy, choice, or juice quality based on thrips and mite scarring. Bars in column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

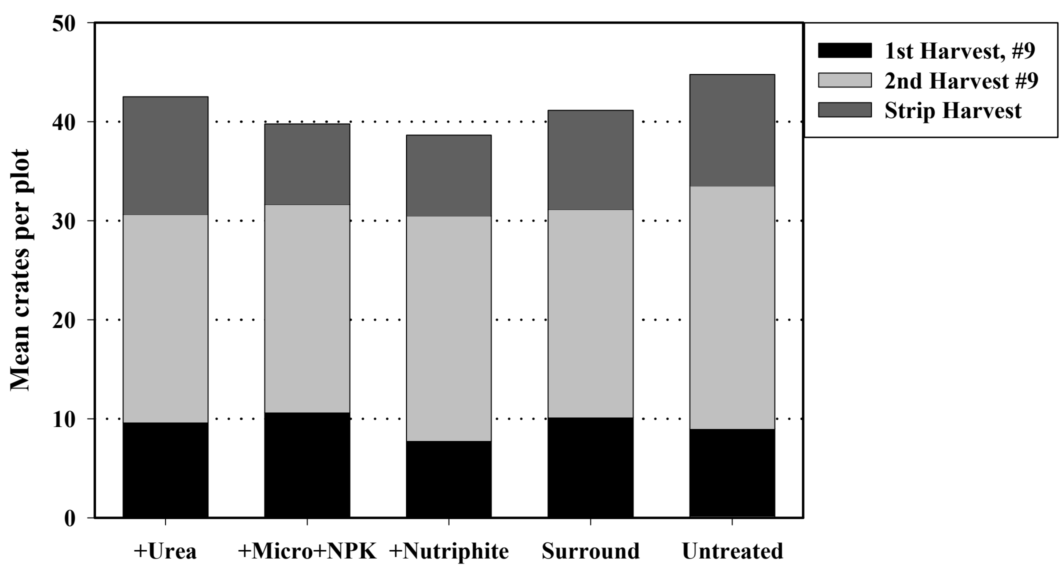

Figure 12. Yield of lemons from plots treated with Surround alone or tank-mixed with foliar fertilizers (first harvest on 11 October 2002, second harvest on 21 November 2002, strip harvest on 02 February 2003). Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

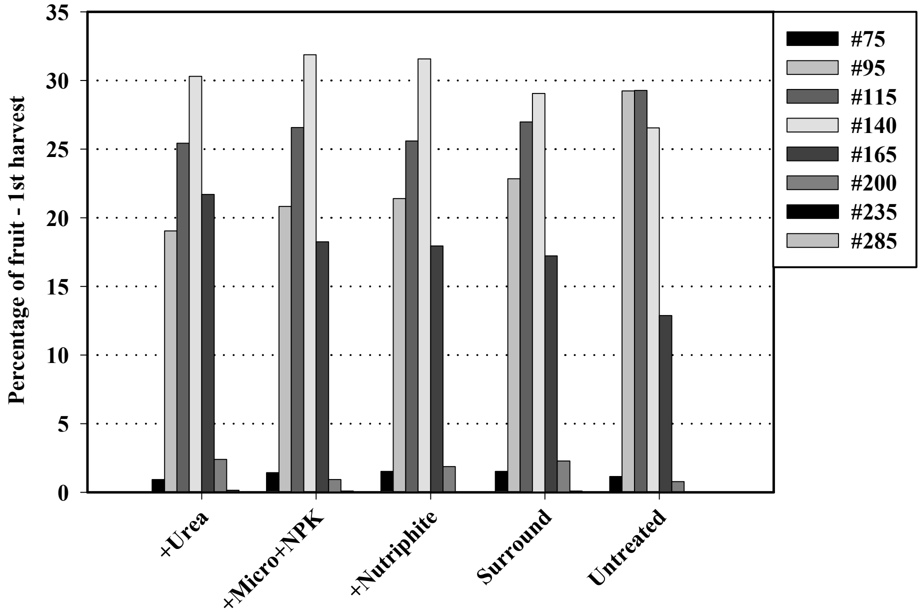

Figure 13. Effects of Surround alone and mixed with foliar fertilizers on fruit size at first harvest (#9 ring), on 11 October 2002. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

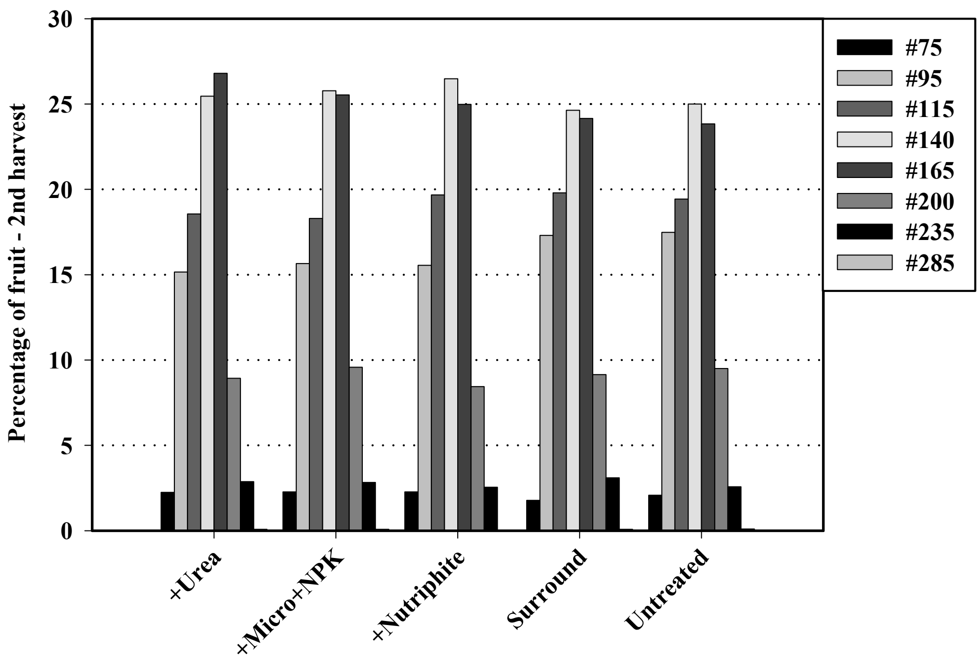

Figure 14. Effects of Surround alone and mixed with foliar fertilizers on fruit size at second harvest (#9 ring), on 21 November 2002. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

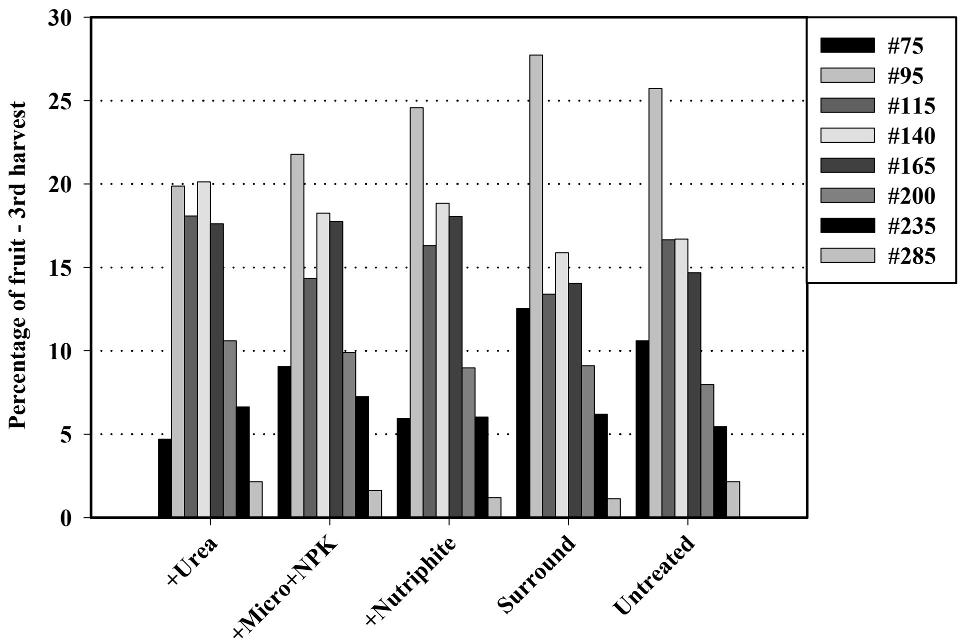

Figure 15. Effects of Surround alone and mixed with foliar fertilizers on fruit size at third harvest (stripped), on 2 February 2003. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

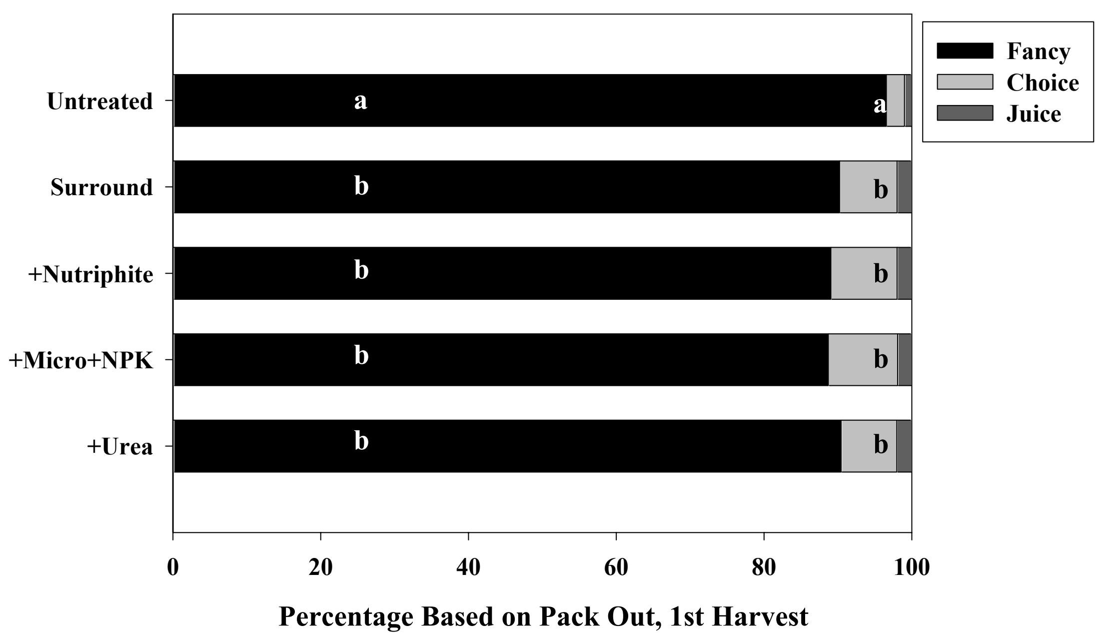

Figure 16. Effects of Surround alone and mixed with foliar fertilizers on fruit pack out quality, 1st harvest 11 October 2002 . Bars in column followed by the same letter are not significantly different based on an F protected ($P<0.05$) LSD. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

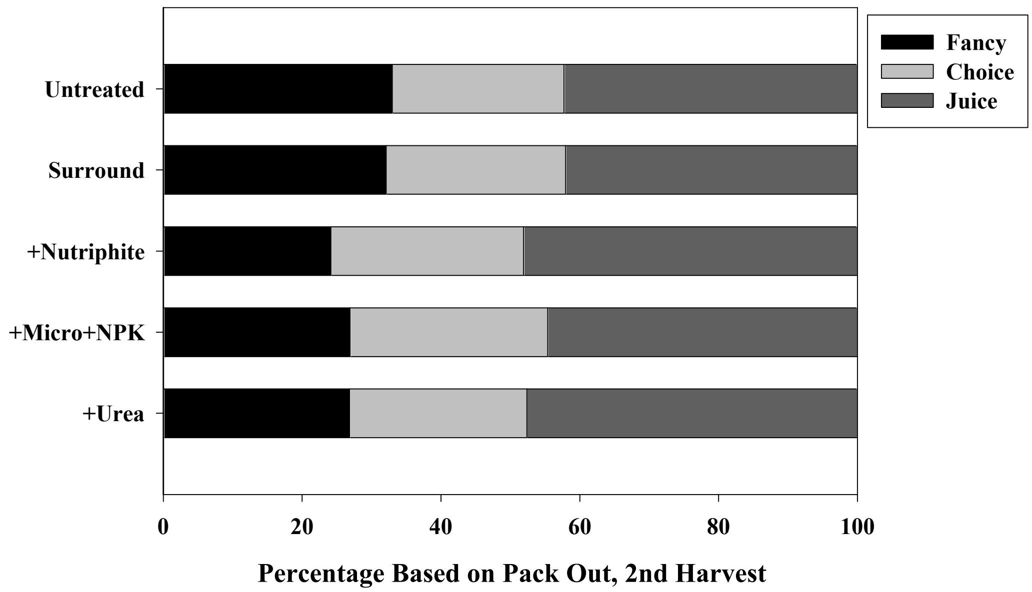

Figure 17. Effects of Surround alone and mixed with foliar fertilizers on fruit pack out quality, 2nd harvest 21 November 2002. No significant difference based on an F protected (P<0.05) LSD. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

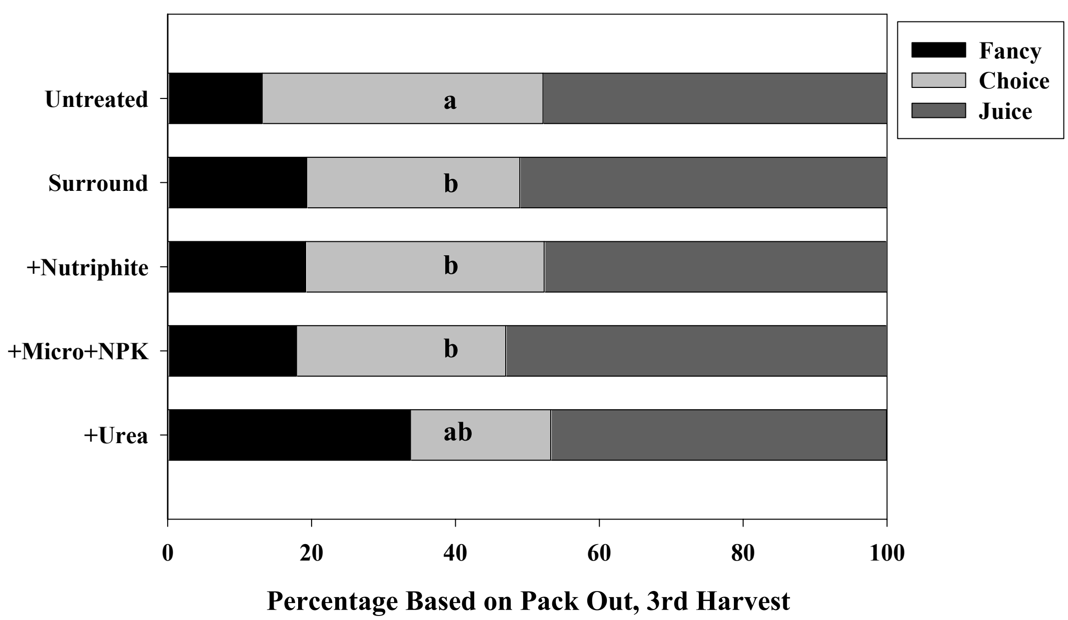

Figure 18. Effects of Surround alone and mixed with foliar fertilizers on fruit pack out quality, 3rd harvest 2 February 2002. Bars in column followed by the same letter are not significantly different based on an F protected (P<0.05) LSD. Nutri = Nutriphite; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK; urea = foliar urea.

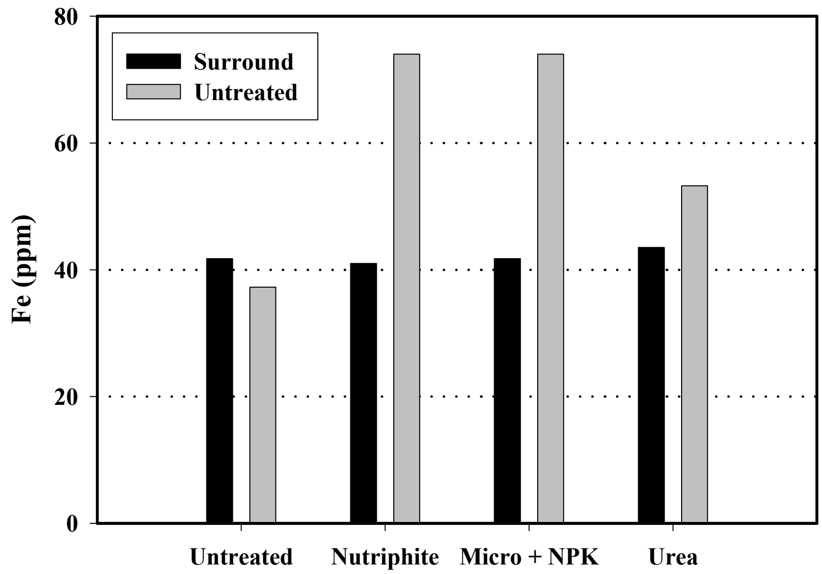

Figure 19. Interaction between foliar fertilizers and Surround on Fe content in lemon leaves on 6 June 2002. Treatments applied 12 April and 19 May, 2002. Fe content on 11 April before applications = 57.83 ppm across treatments. Nutriphite applied at 2 qts/ac; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK applied at 2 qts/ac + 2 lbs/ac; urea = foliar urea applied at 7 lbs/ac. Surround was applied at 50 lbs/ac.

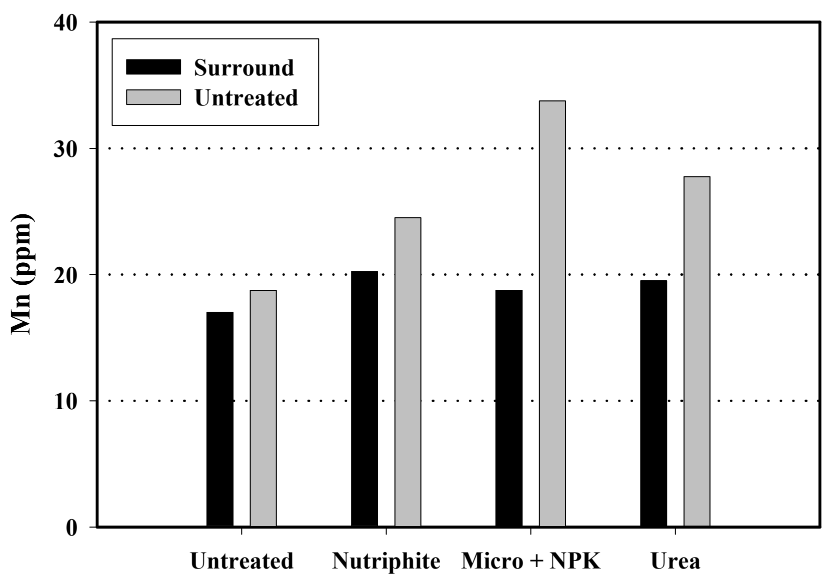

Figure 20. Interaction between foliar fertilizers and Surround on Mn content in lemon leaves on 6 June 2002. Treatments applied 12 April and 19 May, 2002. Mn content on 11 April before applications = 17.33 ppm across treatments. Nutriphite applied at 2 qts/ac; Micro+NPK = Fe, Zn, Mn lignosulfonate + 20-20-20 NPK applied at 2 qts/ac + 2 lbs/ac; urea = foliar urea applied at 7 lbs/ac. Surround was applied at 50 lbs/ac.

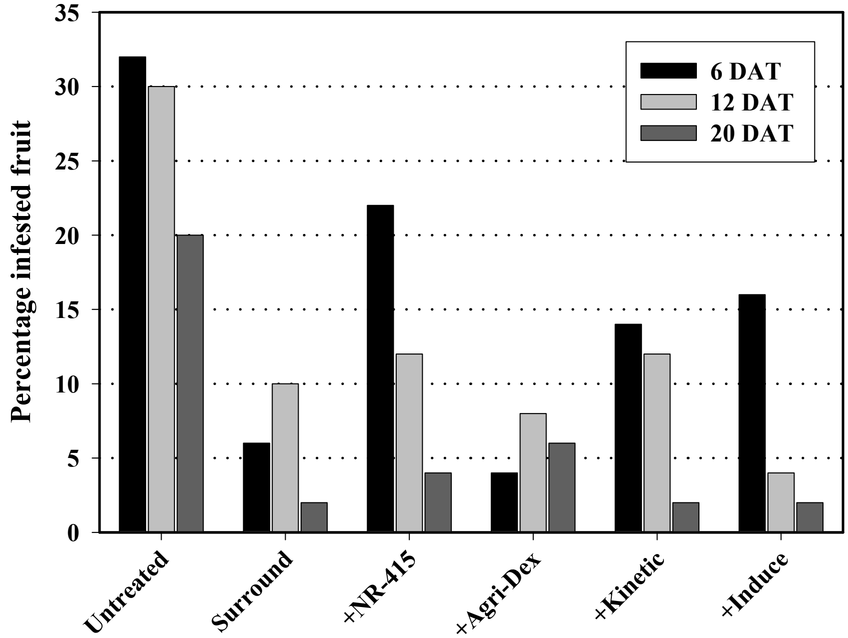

Figure 21. Percentage of lemon fruit infest with one or more immature citrus thrips after being treated with Surround alone or tank-mixed with surfactants. Surround was applied at 50 lbs/A, NR-415 at 1 gal/A, Agri-Dex at 0.125% v/v, Kinetic at 0.1% v/v, and Induce at 0.125% v/v. The spray volume was 100 gal/A.